



Report of Calibration

NIST Service ID Number 76101C
Time Measurement & Analysis Service



Time and Frequency Division
National Institute of Standards and Technology
Boulder, CO 80305-3328

Customer:	Arecibo Observatory UMET #17 Arecibo, PR 00612	Date of Report:	August 5, 2014
		Device Under Test (DUT):	Arecibo Station Clock
Contact:	Dana Whitlow	Period of Calibration:	July 2014

I. Description of Calibration Procedure

The calibrations were performed at the customer's site using a computer-controlled data acquisition system. The calibrations are monitored from the NIST laboratories in Boulder, Colorado through an Internet connection, and NIST personnel compile the data used in this report.

Traceability to the International System of units (SI) through UTC(NIST) is established by using a Global Positioning System (GPS) common-view technique. This technique and supporting references are provided in:

M. A. Lombardi and A. N. Novick, "Remote Time Calibrations via the NIST Time Measurement and Analysis Service," *Measure: The Journal of Measurement Science*, vol. 1, no. 4, pp. 50-59, December 2006.

II. General Information

NIST supplies the hardware, software, and calibration method used to perform the calibration. When measurement system components fail, NIST is responsible for replacing them. When possible, this is done using an overnight delivery service.

Since calibrations are made at the customer's site, maintaining an acceptable laboratory environment is the responsibility of the customer. The customer is also responsible for following the installation and operating procedures outlined in the *Operator's Manual* supplied with each measurement system.

III. Table of Daily Time Differences between DUT and UTC(NIST)

Daily estimates of the time difference between the DUT and UTC(NIST) are provided in Table 1. These daily estimates are obtained by making continuous common-view GPS measurements over a 24-hour period. Table 1 contains an estimate of measurement uncertainty for each time difference ($k = 2$) and provides comments when necessary. A statement of time measurement uncertainty is provided in Section IV. All time measurement units are in nanoseconds.

The results provided herein were obtained under the authority granted by Title 15 United States Code Section 3710a. As such, they are considered confidential and privileged information, and to the extent permitted by law, NIST will protect them from disclosure for a period of five years, pursuant to Title 15 USC 3710a(c)(7)(A) and (7)(B).

Table 1. Daily Time Difference Values and Measurement Uncertainties

<i>Date</i>	<i>MJD</i>	<i>DUT – UTC(NIST) (ns)</i>	<i>Uncertainty U_c ($k = 2$), ns</i>	<i>DUT – UTC(NIST) (frequency)</i>	<i>Corr. Coef. (r)</i>	<i>Comments</i>
7/1/2014	56839	-116.41	±12	-8.4×10^{-14}	-0.38	
7/2/2014	56840	-116.29	±12	-9.7×10^{-14}	-0.35	
7/3/2014	56841	-115.27	±12	-6.4×10^{-14}	-0.37	
7/4/2014	56842	-116.65	±12	-1.6×10^{-13}	-0.61	
7/5/2014	56843	-115.75	±12	-1.0×10^{-13}	-0.32	
7/6/2014	56844	-117.45	±12	-1.4×10^{-13}	-0.43	
7/7/2014	56845	-110.28	±12	-7.8×10^{-14}	-0.36	
7/8/2014	56846	-112.13	±12	-2.0×10^{-13}	-0.59	
7/9/2014	56847	-115.37	±12	-1.1×10^{-13}	-0.41	
7/10/2014	56848	-108.91	±12	-3.8×10^{-14}	-0.19	
7/11/2014	56849	-108.77	±12	$+4.6 \times 10^{-15}$	+0.02	
7/12/2014	56850	-109.86	±12	-7.9×10^{-14}	-0.42	
7/13/2014	56851	-108.87	±12	-8.3×10^{-14}	-0.29	
7/14/2014	56852	-111.53	±12	-1.5×10^{-14}	-0.11	
7/15/2014	56853	-109.91	±12	-4.4×10^{-14}	-0.30	
7/16/2014	56854	-111.06	±12	-4.8×10^{-14}	-0.34	
7/17/2014	56855	-114.39	±12	-3.4×10^{-14}	-0.32	
7/18/2014	56856	-114.05	±12	-8.0×10^{-15}	-0.05	
7/19/2014	56857	-113.45	±12	-9.4×10^{-14}	-0.62	
7/20/2014	56858	-112.93	±12	-5.4×10^{-15}	-0.07	
7/21/2014	56859	-113.81	±12	$+1.1 \times 10^{-15}$	+0.01	
7/22/2014	56860	-114.47	±12	-2.0×10^{-14}	-0.18	
7/23/2014	56861	-114.14	±12	-3.2×10^{-14}	-0.31	
7/24/2014	56862	-114.70	±12	$+1.2 \times 10^{-14}$	+0.09	
7/25/2014	56863	-112.99	±12	-4.8×10^{-14}	-0.43	
7/26/2014	56864	-111.71	±12	$+8.4 \times 10^{-14}$	+0.78	
7/27/2014	56865	-110.65	±12	$+1.7 \times 10^{-14}$	+0.17	
7/28/2014	56866	-111.65	±12	-5.5×10^{-14}	-0.40	
7/29/2014	56867	-111.67	±12	$+6.3 \times 10^{-14}$	+0.39	
7/30/2014	56868	-109.62	±12	-8.0×10^{-14}	-0.42	
7/31/2014	56869	-109.59	±12	$+2.6 \times 10^{-14}$	+0.14	

IV. Statement of Time Measurement Uncertainty

Table 2 provides a statement of time measurement uncertainty. The uncertainty statement uses the root-sum-square (RSS) method described in the *ISO Guide to the Expression of Uncertainty in Measurement* and in *NIST Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*.

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Table 2. Measurement results and statement of measurement uncertainty.

<i>Results</i>	<i>Value</i>	<i>Comments</i>
Baseline (km)	4311.021	Distance between NIST and customer.
Average frequency offset	1.3×10^{-15}	Average frequency offset for month computed from slope of phase, all data included.
Frequency Stability	3.0×10^{-14}	Allan deviation* for month at $\tau = 1$ day.
Time Stability	1.52	Time deviation* for month at $\tau = 1$ day.
Average time offset	-112.72	Average time offset for month, all data included.
<i>Measurement Uncertainty Components (nanoseconds)</i>		
$U_A, \sigma_x(\tau)$	~2	Time deviation* for month at $\tau = 1$ day
U_B , Calibration	4	Uncertainty of initial NIST calibration
U_B , Coordinates	1	Uncertainty of NIST and TMAS antenna coordinates
U_B , Environment	3	Delay changes in TMAS equipment due to temperature and other environmental factors
U_B , Multipath	2	Uncertainty due to multipath reflections
U_B , Ionosphere	2	Uncertainty of broadcast ionospheric delay corrections applied to TMAS measurements
U_B , Ref. delay	0.50	Uncertainty of cable delay measurements (cable connected to DUT)
U_B , Resolution	0.05	Resolution Uncertainty of TMAS unit
$U_C, k = 2$	12	Combined Standard Uncertainty of Daily Time Differences in Table 1

* Allan deviation and Time deviation are described in: "IEEE Standard Definitions of Physical Quantities for Fundamental Frequency and Time Metrology – Random Instabilities," IEEE Standard 1139-1999, prepared by *IEEE Standards Coordinating Committee 27 on Time and Frequency*, March 1999.

This report allows the customer to show traceability to the SI through the national standard of frequency and time interval maintained at NIST.

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